UCRL-JC-135518
PREPRINT

Inertial Fusion Energy (IFE) Concepts, Target Physics Subgroup

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This paper was prepared for submittal to the
Fusion Summer Study
Snowmass, CO
July 11-23, 1999

July 1, 1999

Inertial Fusion Energy (IFE) Concepts
Target Physics Subgroup

Summary
The target physics subgroup met for three days of three hour sessions and discussed several questions:
Session 1A: What are the key scientific issues for validating each target concept and how can they be resolved? Session chairman: Max Tabak
Session 1B: How can existing (and new?) facilities be used to test each concept? Session chairman: Jill Dahlburg
Session 1C: 1) What IFE target physics issues will not be resolved on NIF? 2) What is required to get to high yield?; and 3) What is the significance to IFE of experimentally demonstrating high yield / high gain ? During the discussions, the third question actually turned into a debate concerning the related question of whether or not a single-shot high yield facility is necessary prior to the ETF. Session chairman: Rick Olson

Three inertial fusion concepts were discussed: indirect drive, direct drive and the emerging concept fast ignition. Also discussed was the emerging concept, magnetized target fusion. The results of these discussions are summarized below in sections describing each morning's proceedings. In Session1A, the concepts were sketched; difficulties described and research programs laid out. The established concepts, direct and indirect drive with lasers, have benefited from decades of study and have established through detailed comparisons between experiment and theory a first principles understanding of many of their critical scientific issues: materials properties, hydrodynamic stability and symmetry control. In other areas, such as electron transport or laser-plasma instabilities, there is an adequate empirical basis to proceed, but a complete first principles understanding may be absent. In the design of targets driven by Z-pinches or heavy ion beams much of this understanding carries over. Fast ignition, while promising significantly higher target gains and more relaxed implosion requirements than other inertial fusion concepts, has the greatest physics uncertainties, particularly in the areas of laser light and hot electron transport. Magnetized target fusion is a batch burn concept that uses dense walls to implode a preheated plasma and magnetic fields to reduce thermal conduction losses.

A number of existing or planned facilities can be used to validate these concepts. Apart from doing physics experiments (Rayleigh-Taylor instability, material properties and others), the National Ignition Facility (NIF) will be the integration-validation test for direct and indirect drive and possibly for fast ignition. The Nike laser at the Naval Research Laboratory has the smoothest beams of any fusion laser. These smooth beams can be used to study the Rayleigh-Taylor instability in planar geometry. The Omega laser at the University of Rochester, a Nova scale laser, can be used to study direct drive and indirect drive implosions, and NIF-relevant hohlraum schemes among a variety of physics issues. The Z-machine at Sandia National Laboratory, Albuquerque can be used to study Z-pinch implosion physics, NIF foot physics, radiation flow for Z-pinch driven ignition schemes and even magnetized target fusion. Magnetized target fusion can also be studied at ATLAS, to be constructed by Los Alamos National Laboratory, and at Shiva-Star at the Air Force Research Laboratory. Heavy ion accelerators like that at GSI in Germany and the proposed Integrated Research Experiment(IRE) can study heavy ion deposition physics and responses in heated plasmas. Fast Ignition can be studied on the Vulcan laser (50 J, 50 terawatt) at Rutherford-Appleton Laboratory, at Gekko (50J now-500 J) at ILE, Osaka as well as other facilities in the United States, Germany and France. An ignition demonstration would require tens of kilojoules of pulsed compressed light. A goal of the Fast Ignition effort is to justify this expenditure on the NIF.

Although pursuing ignition on the NIF is a Defense Programs/DoE funded activity it is critical to the IFE mission. Ignition on the NIF will validate much implosion and thermonuclear burn physics, but a balanced program involving Office of Fusion Energy Sciences (OFES) is still required in target physics. Energy conversion issues specific to other drivers like ion beams or Z-pinches can't be studied on the NIF. Fast Ignition research is currently outside the DP program. The mainline direct and indirect laser schemes to be tested on the NIF are inconsistent with liquid wall protection schemes. New designs are needed. The current NIF laser indirect drive point design does not lead to adequate gain with affordable lasers. Heavy ion fusion is not DP-funded at all.

Is a separate high yield facility necessary before an Engineering Test Facility (ETF) is built and what are possibilities for it? New designs may demonstrate high yield on the NIF as constituted or with some upgrade. A $1-2 B Z-pinch may also achieve high yield as might a heavy ion driver in the same price range. Ultimately, we need to demonstrate high gain before the DEMO energy conversion unit is built, but 25 MJ yields are adequate to test engineering features in an ETF.

Question 1A: What are the key scientific issues for validating each target concept and how can they be resolved? Session chairman: Max Tabak Speakers: John Lindl, Jill Dahlburg, Michael Key, Irv Lindemuth, and Friedwardt Winterberg

Indirect drive

In indirect drive, the most studied inertial fusion scheme, energy from an outside source such as laser light, an ion beam or the kinetic energy in Z-pinch is converted into x-rays. These x-rays then transport from the location where they are created to the implosion capsule where they are absorbed by the ablator. The reaction to the expansion of the heated ablator material then drives the capsule implosion. Ignition relies on the formation of a hotspot (with scale that of an alpha particle range) which accumulates much of the energy of the implosion. Burn then propagates to the high-density main fuel where the bulk of the yield is produced.

This scheme allows the separation of capsule implosion physics from driver coupling physics; so ignition on the NIF would validate implosion capsule designs for other drivers. In particular, thermonuclear burn physics, adiabat control through control of the temporal history of the radiation temperature, and hydrodynamic stability of the implosion would be validated on the NIF. Models of radiation transport can also be validated with laser facilities.

There are driver specific issues, however. For laser drivers, the laser-plasma interaction is a critical issue. Although this coupling physics is not completely understood, the work during the NOVA Technical Contract and more recently shows that laser-plasma instabilities can be adequately controlled through beam smoothing. Because current laser efficiencies are typically 10% or less, target gain is a critical issue. The efficiency-gain product should exceed 8-10 for adequate cost of electricity. The current baseline laser targets have insufficient gain. However, preliminary calculations of new designs with improved coupling efficiency from hohlraum to capsule show that indirect drive with lasers should not be ruled out at this time.

Current heavy ion target designs have more than adequate gain in integrated ion-beam deposition/radiation-hydrodynamics/thermonuclear burn calculations (130 at 3MJ) given driver efficiencies in the 25-40% range. Capsule stability is thought to be acceptable, based on single mode growth factor calculations. The growth factors calculated are less than or equal to those calculated for the NIF point design where very detailed 2D/3D multimode calculations have been performed. Similar calculations are required for the heavy ion designs. The detailed deposition profile for ion beams and the hydrodynamic response of the converter to the deposited energy affect the locations of radiation generation and hence the illumination symmetry on the capsule. However, by varying converter properties in the hohlraum the capsule design can accommodate various deposition profiles. There is an ongoing European program to measure and understand heavy ion stopping powers. Also, preheat of the capsule may be caused by radiative relaxation of the atomic states of the in–flight ions or by the nuclear fragmentation of the incident ions. These effects are estimated not to be critical based on measured nuclear fragmentation cross sections and calculated atomic relaxation rates. The sensitivity to beam pointing and power balance can be addressed with 2D/3D radiation-hydrodynamic codes.

There are currently three schemes to drive capsules with x-rays produced by Z-pinches. Two of these schemes involve producing radiation in primary hohlraums and then transporting the radiation to a secondary hohlraum that holds the implosion capsule. For these designs, the major issues are the coupling efficiency from the primary hohlraum to the implosion capsule and the symmetry and temporal history of the radiation driving the capsule. The third Z-pinch design, the so-called dynamic hohlraum involves imploding a Z-pinch wire array upon foam that surrounds the implosion capsule. This design has much higher coupling efficiency than the prior two. The issues here are the stability of the wire array, its effect on the symmetry of the radiation field and the temporal history of the intensity of the radiation. These issues can be resolved by a combination of 2D/3D MHD calculations and experiments with Z-pinches.

Some target design issues involve interactions with reactor design and target fabrication requirements. For instance, the hohlraum materials chosen must be easy to recycle, minimize the induced radioactivity and have high opacity. The target must also be inexpensive to fabricate. Green light is less stressing for laser design than blue light. It is not a favored option for target design/plasma physics reasons. Can the new beam smoothing options coupled with lower intensity target designs make this an acceptable option? Current laser illumination schemes place beams over 2_ steradians. This is not consistent with current liquid first-wall reactor-concepts. New target designs are needed to remedy this. On the other hand, heavy ion targets are limited only by the packing requirements of the final magnetic focussing elements in the reactor wall. Relaxing the beam spot requirement is the challenge for heavy ion target design.

Direct drive

Direct drive has a simple pellet, good coupling efficiency because it avoids the energy conversion phase of indirect drive, and like all IFE concepts a driver removed from the target chamber. It shares many critical issues with indirect drive: efficient coupling, keeping fuel on a low adiabat, demonstrating implosion symmetry, and demonstrating sufficient target stability. There are very efficient designs that use ion beams to directly illuminate a capsule. However, the hydrodynamic stability properties of these designs are suspect. 2D/3D hydrodynamic calculations coupled with future experiments on IRE would be required to settle the issue. For now, direct drive is primarily a laser concept.

Of the direct drive issues the most stressing is hydrodynamic stability. Most schemes raise the ablator adiabat to increase ablation stabilization. A recent design uses radiation produced in an outer high-Z layer to engineer a tailored adiabat that is RT stable at the ablation front (high-adiabat) and yet maintains cold (low-adiabat) ignition-appropriate conditions in the inner fuel region. 1-D calculations for this design produce gain 130(when zooming is used) at 1.3 MJ, raising the gain curve a factor of three from earlier designs. No integrated 2-D multimode calculations have been carried through to burn for this design. Current calculations also do not include the effects of magnetic fields. Ultimately some 3-D hydrodynamic calculations will be needed as well as planar and convergent Rayleigh-Taylor experiments.

Experiments are ongoing at the University of Rochester and NRL leading to hoped-for validation experiments on the NIF. The current experiments will provide equation of state and opacity data, beam energy balance limits and Rayleigh-Taylor growth rates to benchmark the computer codes.

Direct drive may require somewhat better DT ice and ablator finishes than does indirect drive. There is an ongoing target fabrication effort to meet these requirements. The current direct drive designs require reactor perforations spread over 4__steradians_ This is not consistent with liquid wall reactor designs. New target designs may be required. Individual laser beams must be aimed to 25-micron accuracy in order to achieve good symmetry without sacrificing coupling efficiency (Note: It is possible to relax the pointing accuracy by overfilling the beams. This does reduce coupling efficiency). If the final optics is placed at 25 meters to protect them from x-ray and neutron damage, this translates to a 1 microradian pointing requirement.

<u>Fast Ignitor</u>

Fast ignition relies on a somewhat different ignition scheme from conventional direct or indirect drive. Instead of igniting in a hotspot in the center of the fuel formed during the implosion, a fast-ignited capsule will be ignited by an external energy source like a short pulse laser on the capsule surface after the fuel has stagnated. The implosion can be accomplished with lasers, ion beams or Z-pinches. Because ignition occurs after implosion, hydrodynamic instabilities can't quench the burn. Because the Fast Ignitor's compressed state has lower density than that of the conventional implosion, symmetry requirements can be relaxed somewhat. The nominal gain curve for Fast Ignition is a factor 5-10 above the conventional gain curves. This higher gain can be traded for fuels with low tritium loading or smaller driver energy. The resistance to mix implies relaxed target fabrication requirements. It may also be possible to relax some of the cryogenic requirements. If it works, the integrated IFE story becomes stronger. Unfortunately, there is no integrated calculation at this time.

The major issue for the Fast Ignitor is coupling the ignition energy from the short pulse laser to the high-density ignition region. This issue is comprised of three others: transport of laser light close to the assembled fuel, coupling of laser light to hot electrons at critical density and transport of hot electrons from the critical density to the ignition region. Assembling the compressed fuel ablatively creates an overdense plasma with scale dimension comparable to the initial capsule radius. Ponderomotively boring holes through a long plasma may prove difficult. Non-spherical implosion designs may reduce the scale of the coronal plasma where the ignitor beam would enter and simplify this problem. These implosion calculations can reliably be performed with existing codes. PIC codes predict laser-electron coupling efficiencies between 40% and 90%. Efficiencies above 40% have been measured in some experiments. Transport of the hot electrons between the critical surface and the ignition region has quite rich physics with many possible plasma instabilities. The forward currents are 10^4-10^5 Alfven currents, so magnetic fields and current and charge neutralization should be important. Magnetic fields, depending on the simulation technique, between 10's and 100's of megagauss are predicted. This physics must be investigated with a research program that supports laboratory experiments together with a 3D parallel PIC code and with a hybrid code that can deal with high background electron densities. The experiments should study holeboring through overdense plasmas, electron transport through highly compressed matter and aspherical implosions.

Near term experiments can be carried out with a single Petawatt class laser beam coupled with a high-energy long-pulse beam for plasma formation. If positive conclusions follow from this concept exploration, an ignition demonstration at NIF can be envisaged. This would require converting up to 10% of the NIF beams to short pulse ignitor beams and using the remaining beams for fuel compression. A bottom line economic question that affects the technology is: how much ignitor energy will be required to make the concept robust?

Magnetized Targets

Magnetized target fusion is an emerging concept between magnetic confinement and inertial confinement. In this approach, a preheated plasma with an embedded magnetic field is squeezed by a liner implosion to ignition conditions. The magnetic field reduces the thermal conduction losses while the liner confines the plasma and supplies the energy required to heat it. The magnetic field allows lower implosion velocities and hence driver powers than IFE while the inertial confinement of the fuel allows lower stored magnetic field energy than MFE.

There are several issues. This is a batch burn concept. It was unclear how to refuel the target after ignition was obtained. Will the Q be big enough for IFE? There have been no MHD calculations demonstrating a target with Q large enough for an energy mission. The tools are available to do this calculation and it should be done. A small amount of high Z pollutant injected into the plasma will radiatively cool the plasma and kill ignition. Are there designs that minimize mix and still have adequate Q?

The development cost for this concept is low because there is little capital expenditure for experiments. The experiments can be conducted on existing facilities.

Question 1B

"How can existing (and new?) facilities be used to test each concept?"

The session was comprised of seven talks and discussion. The talks (and speakers) were: [1] NIF (John Lindl); [2] OMEGA (Richard Town); [3] Nike (Jill

Dahlburg); [4] Z (Rick Olson); [5] GSI (Max Tabak); [6] Liner Drivers (Irv Lindemuth); [7] Addition to NIF (PW) for Fast Ignitors (Mike Key). Following are summaries of the key points of each talk and associated issues.

[1] NIF (John Lindl).

KEY POINT: The NIF will enable integration experiments which include: gain energetics; pulse shape and compression; hydrodynamic stability and impact on direct drive; symmetry for indirect drive; and ignition and burn.

Q: What is the metric for success?
A: Target gain.

Information obtained from NIF experiments will carry over to:
(a) heavy ions (e.g., capsule physics; symmetry control; and, hohlraum energetics);
(b) direct drive (e.g., hydrodynamic stability (imprint and target fabrication); and
(c) maybe even be able to test the fast ignitor concept (see talk [7]).

[2] OMEGA (Richard Town).

KEY POINT: A range of integrated direct drive and indirect drive experiments are being performed on the OMEGA laser at URLLE.

OMEGA is a 60 beam, 30 kJ laser with 1-2 % beam-to-beam nonuniformity and pulse shape duration ranging from 100 ps to 3 ns. Presently the bandwidth is 0.25 THz, with 1 THz on line in June 2000. A range of target types is fielded on OMEGA. These include: spherical warm pellets; direct drive cylinders, 'scale 1' hohlraums; planar targets; tetrahedral hohlraums; and, shock-tube hohlraums.

Q: How well must a cryogenic direct drive pellet do on OMEGA to go ahead with direct drive on the NIF?
A: 10 percent of 1-D yield. (This is a reasonable expectation, since currently 1 percent is achieved with warm, alpha = 3 targets.)

[3] Nike (Jill Dahlburg).

KEY POINT: Nike is a flexible, uniform laser that is addressing outstanding physics issues that determine the success of a direct drive ICF pellet.

Nike is a 2-3KJ laser capable of the most uniform target illumination of all high-energy lasers suitable for fusion. The large bandwidths (3 THz) and advanced beam smoothing available with Nike allow better than 0.2 percent effective time-averaged illumination uniformity when overlapping 40 beams on planar targets. Nike experiments examine laser imprint, hydrodynamic instability, equations of state (EOS) for ICF materials, and other physics issues related to ICF. Nike provides the temporal laser pulse shapes needed to simulate the low isentrope compression and acceleration of pellet shells needed for high gain implosions. Peak intensities of up to 2e14 W/cm^2 are available for planar-target acceleration experiments. The planar geometry allows superior diagnostic access and allows acceleration of targets whose thickness approaches that of high gain target shells with modest laser energy. The Nike diagnostic suite includes high resolution, single line crystal x-ray imagers that are used to detect the lateral mass flow due to hydrodynamic instability in laser-accelerated targets.

Nike experiments are fielded to address the design criteria for high pellet gain, with particular emphasis on control of the target isentrope and inhibition of the Rayleigh-Taylor instability. In initial work, very low levels of laser imprint, equivalent to better than 100 Angstroms surface finish, were inferred from plastic targets accelerated with the Nike uniform illumination. Recent work has concentrated on examining the underlying physics of advanced target designs where the ablator is preheated but the fuel remains cold. This work includes hydrodynamic instability measurements with x-ray preheated plastic and deuterium-loaded foam targets; EOS measurements of candidate materials
including foams and deuterium loaded foams; and emission measurements of x-ray producing layers in targets that preheat the ablator and that may also ameliorate laser imprint.

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[4] Z (Rick Olson).
KEY POINT: The large volume, long pulselength hohlraums together with an extensive suite of x-ray and shock diagnostics on Z offer the opportunity to study a number of key physics issues relevant to indirect-drive ICF target concepts.

The Z pulsed-power facility is presently capable of providing hohlraum drives with pulselengths ranging from ~3 ns to ~15 ns in length and peak hohlraum x-ray input powers of up to ~15 TW in small (~6 mm diameter) hohlraums and ~30 TW in large (~12 mm diameter) hohlraums. Hohlraum temperatures on Z range from ~80 eV in long-pulse, large hohlraums to ~150 eV in short-pulse, small hohlraums. The Z diagnostic suite includes XRD arrays, transmission-grating spectrometers, PCD arrays, soft x-ray framing cameras, laser velocity interferometry, and a laser active shock breakout system. A laser backlighter system will also be available on Z beginning in about 2001.

The ~80-150 eV x-ray driven hohlraums on Z provide a platform for studying a number of the key physics issues of indirect-drive ICF targets. These include: hohlraum energetics, hohlraum wall opacity, wall motion in filled hohlraums, hohlraum hole closure, capsule ablator EOS, DT EOS, shock propagation in capsule ablator materials, and ablator burnthrough. In addition, a number of issues that are specific to z-pinch driven indirect-drive ICF concepts can also be studied with the Z facility. These include z-pinch implosion energetics and reproducibility, temporal shaping of the x-ray drive, x-ray transport and symmetrization, and capsule preheat.

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5. GSI (Max Tabak).

KEY POINT: GSI provides a capability to measure changes in ion packet energy as those packets are propagated through laser-produced plasmas. It can provide stopping power data relevant to heavy ion fusion.

The plasmas are produced with a 100J on-site laser, which heats foils. Ion beams are passed through the expanding plasma. Ion packet energy modification can be inferred from measured changes in ion packet arrival times.

6. Magnetized Target Fusion (MTF) Liner Facilities (Irv Lindemuth).

Although any implosion driver can be considered as an implosion driver candidate for magnetized targets, MTF advocates have chosen magnetically driven liners as the lowest cost path to evaluating the principles of MTF and demonstrating a burning plasma.

Because of existing and near-term pulsed power facilities (e.g, ShivaStar at AWRL and Atlas at LANL); liner-driven MTF can be explored without any major capital investment. A recent OFES-funded liner experiment on ShivaStar demonstrated liner performance suitable for significantly compressing a field-reversed configuration. The 30 cm long liner had an initial radius of 5 cm. Radiographs and other diagnostics indicated that the liner achieved a kinetic energy of 1.4 MJ, with excellent symmetry at a radial

convergence of 12. The Atlas facility, operational in 2001, will be able to drive MTF liners to more
than 10 MJ at MTF-relevant velocities.

7. Addition to NIF (PW) for Fast Ignitors (Mike Key).

KEY POINT: A petawatt (PW) laser for full scale NIF Fast Ignition has been demonstrated on the Nova laser.

In order to field a petawatt supplying tens of kilojoules on the NIF, we need to develop transmission gratings for longer pulses, to replace current PW reflection gratings. Other issues (prepulse; deformable mirrors) are not serious. Fast Ignitor relevant experiments, such as the investigation of hole boring, are suggested for other, near term PW lasers, such as SPIRE (a continuation of the Nova-Petawatt program). There is ongoing Fast Ignitor research in the United Kingdom, Japan, France, and Germany in addition to the American program.

Subgroup 1: Targets, Topic 1C, leader: Rick Olson
Date: July 15,1999, attendance: 21 attendees from 9 institutions

This session addressed three specific questions: 1) What IFE target physics issues will not be resolved on NIF? 2) What is required to get to high yield?; and 3) What is the significance to IFE of experimentally demonstrating high yield / high gain ? During the discussions, the third question actually turned into a debate concerning the related question of whether or not a single-shot high yield facility is necessary prior to the
ETF.

Max Tabak (LLNL) and Richard Town (UR/LLE) led discussions concerning the target physics issues that would not be addressed on NIF. Max initiated discussions on four indirect drive issues that either cannot (because it's not possible) or will not (because they're not in the plan) be investigated on NIF. The indirect drive issues are: 1) two-sided illumination where a small solid angle is subtended by laser beams; 2) laser illumination with green light (there was some disagreement on this); 3) physics issues specific to other drivers (eg. ion deposition); and 4) indirect drive implosion coupled to fast ignition. Richard led the discussions concerning direct drive target issues that would not be resolved on NIF. He began by stating that "90% of direct drive issues can be examined on NIF". The remaining 10% that cannot be resolved on NIF include: 1) high yield implosions; 2) high rep rate and target deployment suitable for energy application; and 3) target chamber and final optics material issues. Although there was much group discussion concerning past and potential future experiments on Omega, NIKE, and NIF; the overall conclusions concerning what could not be done in either pre-NIF or NIF experiments remained unchanged from the basic points originally listed by Max and Richard.

Rick Olson (SNL), John Lindl (LLNL), and Mark Hermann (LLNL) led the discussions concerning the second question -- What is required to get to high yield on either the ZX/X1 or the NIF/NIF-upgrade paths? Rick believes that the ZX/X1 path to high yield would require a combination of a ~10 year R&D program and a ~$1B facility. The R&D program would involve experiments (on the existing Z and an intermediate facility called ZX) in the areas of pulsed power, hohlraum energetics, pulse shaping, and symmetry. For IFE, research in the areas of rep-rate, standoff, and reactor chamber concepts would also be required. To indicate the level of extrapolation that the ZX/X1 path would involve, Rick made the comparison that, in terms of $A_w T^4$ (which is proportional to power into a hohlraum), Z is similar to Nova in input power, but also has more energy (longer pulse length). There seemed to be agreement (on the part of SNL and LLNL) that the ZX/X1 path is feasible but not assured. It was pointed out during Rick's presentation that LLNL has also calculated yields of ~400-1000 MJ using the X1 power pulse as input. John Lindl described a potential technique for doing high yield target experiments on NIF. This involves a recently developed "advanced coupling target" employing lower laser power, longer pulse shapes, new wall material mixtures, and larger capsule/hohlraum size with improved coupling efficiency. John described a recent unoptimized, 2D integrated calculation done by Larry Suter (LLNL) indicating ~600 kJ absorbed in a capsule with a ~70 MJ yield. John indicated that straightforward improvements upon Larry's calculation will increase the calculated yield to ~150 MJ. His "guess" for an upper limit on high yield calculations utilizing NIF laser input is ~400 MJ. This is preliminary work in progress. John stated that high yield in NIF is "by no means assured". An item worth noting about the related discussions involves the question of whether or not a new NIF target chamber (~$100M) would be required for high yield experiments. Apparently, it is possible that a limited number of high yield experiments could be done in the existing NIF chamber. In a more general approach to the topic of "What's required for high yield?" Mark Hermann gave a presentation on results from capsule calculations ranging from 20 MJ to > GJ with Tr chosen for 40% ignition margin. His basic conclusion is that bigger is easier - lower Tr is required for the same margin or, if we use a big capsule with 300 eV, it can be very robust.

The third question in this session turned into a debate concerning whether or not a single-shot high yield facility is necessary and/or useful prior to the ETF. John Lindl stated that no new high yield / high gain facility is required prior to the ETF for either target physics or the development path reasons. Keith Matzen (SNL) maintained that high yield / high gain in a single-shot facility is needed for IFE and should be positioned on the roadmap at a time prior to the ETF. John's main points can be summarized as follows: 1) ignition and burn propagation physics is scale-size invariant; 2) differences between ion and laser targets can be tested in nonfusion experiments; 3) ETF requires ~25 MJ capsules (hence does not require high yield capsules); 4) multiple chambers could allow high yield tests in the ETF; and 5) high yield might possible on NIF (as discussed previously). Keith presented a different point of view. He made the following points: 1) the DOE/DP has a high yield mission need and might provide a ~$1B single shot high yield facility; 2) the step from NIF to ETF is "enormous"; 3) the high yield step adds value for IFE target design; 4) the high yield step adds value for IFE chamber design; 5) the high yield step reduces risk for ETF; and 6) the incremental cost to DOE/OFES would be small if DOE/DP funds the facility. There was a significant amount of discussion of the high yield question throughout the entire session (even before John and Keith began their discussions), indicating a range of viewpoints on the issue. Jill Dahlburg and Rick Olson have a rather extensive set of notes from the session, indicating some of the various positions taken by the attendees (who represented nine different research institutions).

Several days later this heated discussion resumed. A consensus developed with few of different opinion: there was no need to build an additional facility along the development path. High yield could be tested in single-shot experiments on the DEMO driver before energy production began on the DEMO. The ETF experiments studying reactor physics issues could be performed at reduced scale and hence reduced cost. For some concepts, it may be possible to upgrade the ETF to high yield and DEMO capability.

This work was performed under the auspices of the U.S. Dept. of Energy at LLNL under contract no. W-7405-Eng-48.